

SYSTEMS FOR MAGNIFICATION AND DISTORTION CORRECTION FOR IMPRINT LITHOGRAPHY PROCESSES

BACKGROUND OF THE INVENTION

[0001] The field of invention relates generally to imprint lithography. More particularly, the present invention is directed to reducing pattern distortions during imprint lithography processes.

[0002] Micro-fabrication involves the fabrication of very small structures, e.g., having features on the order of micro-meters or smaller. One area in which micro-fabrication has had a sizeable impact is in the processing of integrated circuits. As the semiconductor processing industry continues to strive for larger production yields while increasing the circuits per unit area formed on a substrate, micro-fabrication becomes increasingly important. Micro-fabrication provides greater process control while allowing increased reduction of the minimum feature dimension of the structures formed. Other areas of development in which micro-fabrication has been employed include biotechnology, optical technology, mechanical systems and the like.

[0003] An exemplary micro-fabrication technique is shown in United States patent number 6,334,960 to Willson et al. Willson et al. disclose a method of forming a relief image in a structure. The method includes providing a substrate having a transfer layer. The transfer layer is covered with a polymerizable fluid composition. A mold makes mechanical contact with the polymerizable fluid. The mold includes a relief structure, and the polymerizable fluid composition fills the relief structure. The polymerizable fluid

composition is then subjected to conditions to solidify and polymerize the same, forming a solidified polymeric material on the transfer layer that contains a relief structure complimentary to that of the mold. The mold is then separated from the solid polymeric material such that a replica of the relief structure in the mold is formed in the solidified polymeric material. The transfer layer and the solidified polymeric material are subjected to an environment to selectively etch the transfer layer relative to the solidified polymeric material such that a relief image is formed in the transfer layer. The time required and the minimum feature dimension provided by this technique is dependent upon, *inter alia*, the composition of the polymerizable material.

[0004] United States patent number 5,772,905 to Chou discloses a lithographic method and apparatus for creating ultra-fine (sub-25 nm) patterns in a thin film coated on a substrate in which a mold having at least one protruding feature is pressed into a thin film carried on a substrate. The protruding feature in the mold creates a recess of the thin film. The mold is removed from the film. The thin film then is processed such that the thin film in the recess is removed exposing the underlying substrate. Thus, patterns in the mold are replaced in the thin film, completing the lithography. The patterns in the thin film will be, in subsequent processes, reproduced in the substrate or in another material which is added onto the substrate.

[0005] Yet another imprint lithography technique is disclosed by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, *Nature*, Col. 417, pp. 835-837, June 2002, which is referred to as a laser assisted

direct imprinting (LADI) process. In this process a region of a substrate is made flowable, e.g., liquefied, by heating the region with the laser. After the region has reached a desired viscosity, a mold, having a pattern thereon, is placed in contact with the region. The flowable region conforms to the profile of the pattern and is then cooled, solidifying the pattern into the substrate. A concern with these processes concerns distortions in the pattern resulting from, *inter alia*, extenuative variations in the imprinting layer and/or the substrate.

[0006] It is desired, therefore, to provide a system to reduce distortions in patterns formed using imprint lithographic techniques.

SUMMARY OF THE INVENTION

[0007] The present invention is directed toward a system to vary dimensions of a template in order to attenuate, if not prevent, distortions in an underlying pattern formed by the template. To that end, the system features a compression device that includes a pair of spaced-apart contact members to compress a perimeter surface of the template between the pair of spaced-apart contact members. One embodiment of the compression device includes first and second bodies, each has a contact member, defining a pair contact members. The contact members are disposed opposite to each other and spaced apart a distance. The first body includes an actuator arm, and a chamber disposed adjacent to the actuator arm. One of the pair of contact members is coupled to the actuator arm to move in response to movement of the actuator arm, varying the distance from the remaining contact member. A bladder is positioned within the chamber and has a variable volume. The

actuator arm is coupled to the first body to move in response to variations of the volume to vary the distance. In one example, a fluid, such as a gas, selectively ingresses and egresses from the bladder to vary the volume of the same.

[0008] Use of a bladder facilitates conformation of the bladder with the actuator arm. In this manner, non-uniform force distribution on the actuator arm due, for example, to actuator surface imperfections, is avoided. In a similar manner, non-uniform force distribution on the template due, for example, to perimeter surface imperfections, may be avoided by forming one or more of the contact members from compliant material. Reducing, if not avoiding, non-uniform force distributions on the actuator arm and the perimeter surface provides more control and/or higher resolution of dimensional variation of the template. These and other embodiments are discussed more fully below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Fig. 1 is a perspective view of a lithographic system in accordance with the present invention;

[0009] Fig. 2 is a simplified elevation view of a lithographic system shown in Fig. 1;

[0010] Fig. 3 is a simplified representation of material from which an imprinting layer, shown in Fig. 2, is comprised before being polymerized and cross-linked;

[0011] Fig. 4 is a simplified representation of cross-linked polymer material into which the material shown in Fig. 3 is transformed after being subjected to radiation;

[0012] Fig. 5 is a simplified elevation view of a mold spaced-apart from the imprinting layer, shown in Fig. 1, after patterning of the imprinting layer;

[0013] Fig. 6 is a simplified elevation view of an additional imprinting layer positioned atop of the substrate shown in Fig. 5 after the pattern in the first imprinting layer is transferred therein;

[0014] Fig. 7 is a detailed perspective view of a print head shown in Fig. 1;

[0015] Fig. 8 is a cross-sectional view of a chucking system in accordance with the present invention;

[0016] Fig. 9 is an exploded view of an imprint head shown in Fig. 7;

[0017] Fig. 10 is a bottom-up plan view of a chuck body shown in Fig. 8;

[0018] Fig. 11 is a perspective view of an actuator device shown in Fig. 8 and used to vary dimensions of a template;

[0019] Fig. 12 is a cross-sectional view of the actuator device shown in Fig. 11, taken along lines 12-12;

[0020] Fig. 13 is a bottom up view of the actuator device shown in Fig. 12 in accordance with a first alternate embodiment;

[0021] Fig. 14 is a bottom up view of the actuator device shown in Fig. 13 in accordance with a second alternate embodiment;

[0022] Fig. 15 is a bottom up view of the actuator device shown in Fig. 13 in accordance with a third alternate embodiment;

[0023] Fig. 16 is a top down view of a wafer, shown in Figs. 2, 5 and 6 upon which imprinting layers are disposed;

[0024] Fig. 17 is a detailed view of Fig. 16 showing the position of the mold in one of the imprint regions;

[0025] Fig. 18 is a bottom-up plan view of the chuck body shown in Fig. 8 in accordance with an alternate embodiment;

[0026] Fig. 19 is a cross-sectional view of a chuck body shown in Fig. 8 in accordance with a second alternate embodiment;

[0027] Fig. 20 is a flow diagram showing a method of reducing distortions in patterns formed using imprint lithography techniques in accordance with the present invention; and

[0028] Fig. 21 is a flow diagram showing a method of reducing distortions in patterns formed using imprint lithography techniques in accordance with an alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] Fig. 1 depicts a lithographic system 10 in accordance with one embodiment of the present invention that includes a pair of spaced-apart bridge supports 12 having a bridge 14 and a stage support 16 extending therebetween. Bridge 14 and stage support 16 are spaced-apart. Coupled to bridge 14 is an imprint head 18, which extends from bridge 14 toward stage support 16. Disposed upon stage support 16 to face imprint head 18 is a motion stage 20. Motion stage 20 is configured to move with respect to stage support 16 along X and Y axes. An exemplary motion stage device is disclosed in United States patent application number 10/194,414, filed July 11, 2002, entitled "Step and Repeat Imprint Lithography Systems", assigned to the assignee of the present invention, and which is incorporated by reference herein in its entirety. A radiation source 22 is coupled to system 10 to impinge actinic radiation upon motion stage 20. As shown, radiation source 22 is coupled to bridge

14 and includes a power generator 23 connected to radiation source 22.

[0030] Referring to both Figs. 1 and 2, connected to imprint head 18 is a template 26 having a mold 28 thereon. Mold 28 includes a plurality of features defined by a plurality of spaced-apart recessions 28a and protrusions 28b. The plurality of features defines an original pattern that is to be transferred into a wafer 30 positioned on motion stage 20. To that end, imprint head 18 is adapted to move along the Z axis and vary a distance "d" between mold 28 and wafer 30. In this manner, the features on mold 28 may be imprinted into a flowable region of wafer 30, discussed more fully below. Radiation source 22 is located so that mold 28 is positioned between radiation source 22 and wafer 30. As a result, mold 28 is fabricated from material that allows it to be substantially transparent to the radiation produced by radiation source 22.

[0031] Referring to both Figs. 2 and 3, a flowable region, such as an imprinting layer 34, is disposed on a portion of surface 32 that presents a substantially planar profile. Flowable region may be formed using any known technique such as a hot embossing process disclosed in United States patent number 5,772,905, which is incorporated by reference in its entirety herein, or a laser assisted direct imprinting (LADI) process of the type described by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, Nature, Vol. 417, pp. 835-837, June 2002. In the present embodiment, however, flowable region consists of imprinting layer 34 being deposited as a plurality of spaced-apart discrete beads 36 of material 36a on wafer 30, discussed more fully below. An exemplary system for depositing beads 36

is disclosed in United States patent application number 10/191,749, filed July 9, 2002, entitled "System and Method for Dispensing Liquids", and which is assigned to the assignee of the present invention. Imprinting layer 34 is formed from a material 36a that may be selectively polymerized and cross-linked to record the original pattern therein, defining a recorded pattern. An exemplary composition for material 36a is disclosed in United States patent application number 10/463,396, filed June 16, 2003 and entitled "Method to Reduce Adhesion Between a Conformable Region and a Pattern of a Mold", which is incorporated by reference in its entirety herein. Material 36a is shown in Fig. 4 as being cross-linked at points 36b, forming cross-linked polymer material 36c.

[0032] Referring to Figs. 2, 3 and 5, the pattern recorded in imprinting layer 34 is produced, in part, by mechanical contact with mold 28. To that end, imprint head 18 reduces the distance "d" to allow imprinting layer 34 to come into mechanical contact with mold 28, spreading beads 36 so as to form imprinting layer 34 with a contiguous formation of material 36a over surface 32. In one embodiment, distance "d" is reduced to allow sub-portions 34a of imprinting layer 34 to ingress into and fill recessions 28a.

[0033] To facilitate filling of recessions 28a, material 36a is provided with the requisite properties to completely fill recessions 28a while covering surface 32 with a contiguous formation of material 36a. In the present embodiment, sub-portions 34b of imprinting layer 34 in superimposition with protrusions 28b remain after the desired, usually minimum distance "d", has been reached, leaving sub-portions 34a with a thickness t_1 , and

sub-portions 34b with a thickness, t_2 . Thicknesses " t_1 " and " t_2 " may be any thickness desired, dependent upon the application. Typically, t_1 is selected so as to be no greater than twice the width u of sub-portions 34a, i.e., $t_1 \leq 2u$, shown more clearly in Fig. 5.

[0034] Referring to Figs. 2, 3 and 4, after a desired distance " d " has been reached, radiation source 22 produces actinic radiation that polymerizes and cross-links material 36a, forming cross-linked polymer material 36c. As a result, the composition of imprinting layer 34 transforms from material 36a to material 36c, which is a solid. Specifically, material 36c is solidified to provide side 34c of imprinting layer 34 with a shape conforming to a shape of a surface 28c of mold 28, shown more clearly in Fig. 5. After imprinting layer 34 is transformed to consist of material 36c, shown in Fig. 4, imprint head 18, shown in Fig. 2, is moved to increase distance " d " so that mold 28 and imprinting layer 34 are spaced-apart.

[0035] Referring to Fig. 5, additional processing may be employed to complete the patterning of wafer 30. For example, wafer 30 and imprinting layer 34 may be etched to transfer the pattern of imprinting layer 34 into wafer 30, providing a patterned surface 32a, shown in Fig. 6. To facilitate etching, the material from which imprinting layer 34 is formed may be varied to define a relative etch rate with respect to wafer 30, as desired. The relative etch rate of imprinting layer 34 to wafer 30 may be in a range of about 1.5:1 to about 100:1. Alternatively, or in addition to, imprinting layer 34 may be provided with an etch differential with respect to photo-resist material (not shown) selectively disposed thereon. The photo-resist material (not shown) may be

provided to further pattern imprinting layer 34, using known techniques. Any etch process may be employed, dependent upon the etch rate desired and the underlying constituents that form wafer 30 and imprinting layer 34. Exemplary etch processes may include plasma etching, reactive ion etching, chemical wet etching and the like.

[0036] Referring to both Figs. 1 and 2 an exemplary radiation source 22 may produce ultraviolet radiation. Other radiation sources may be employed, such as thermal, electromagnetic and the like. The selection of radiation employed to initiate the polymerization of the material in imprinting layer 34 is known to one skilled in the art and typically depends on the specific application which is desired. Furthermore, the plurality of features on mold 28 are shown as recessions 28a extending along a direction parallel to protrusions 28b that provide a cross-section of mold 28 with a shape of a battlement. However, recessions 28a and protrusions 28b may correspond to virtually any feature required to create an integrated circuit and may be as small as a few tenths of nanometers. As a result, it may be desired to manufacture components of system 10 from materials that are thermally stable, e.g., have a thermal expansion coefficient of less than about 10 ppm/degree centigrade at about room temperature (e.g. 25 degrees Centigrade). In some embodiments, the material of construction may have a thermal expansion coefficient of less than about 10 ppm/degree Centigrade, or less than 1 ppm/degree Centigrade. To that end, bridge supports 12, bridge 14, and/or stage support 16 may be fabricated from one or more of the following materials: silicon carbide, iron alloys available under the trade name INVAR[®], or name SUPER INVAR[™], ceramics, including but not limited to

ZERODUR® ceramic. Additionally table 24 may be constructed to isolate the remaining components of system 10 from vibrations in the surrounding environment. An exemplary table 24 is available from Newport Corporation of Irvine, California.

[0037] Referring to Figs. 7 and 8, template 26, upon which mold 28 is present, is coupled to imprint head housing 18a via a chucking system 40 that includes chuck body 42. Specifically, a calibration system 18b is coupled to imprint head housing 18a, and chuck body 42 couples template 26 to calibration system 18b vis-à-vis a flexure system 18c. Calibration system 18b facilitates proper orientation alignment between template 26 and wafer 30, shown in Fig. 5, thereby achieving a substantially uniform gap distance , "d", therebetween.

[0038] Referring to both Figs. 7 and 9, calibration system 18b includes a plurality of actuators 19a, 19b and 19c and a base plate 19d. Specifically, actuators 19a, 19b and 19c are connected between housing 18a and base plate 19d. Flexure system 18c includes flexure springs 21a and flexure ring 21b. Flexure ring 21b is coupled between base plate 19d and flexure springs 21a. Motion of actuators 19a, 19b and 19c orientates flexure ring 21b that may allow for a coarse calibration of flexure springs 21a and, therefore, chuck body 42 and template 26. Actuators 19a, 19b and 19c also facilitate translation of flexure ring 21b to the Z-axis. Flexure springs 21a include a plurality of linear springs that facilitate gimbal-like motion in the X-Y plane so that proper orientation alignment may be achieved between wafer 30 and template 26, shown in Fig. 2.

[0039] Referring to Figs. 8 and 10 chuck body 42 is adapted to retain template 26 upon which mold 28 is

attached employing vacuum techniques. To that end, chuck body 42 includes first 46 and second 48 opposed sides. A side, or edge, surface 50 extends between first side 46 and second side 48. First side 46 includes a first recess 52 and a second recess 54, spaced-apart from first recess 52, defining first 58 and second 60 spaced-apart support regions. First support region 58 cinctures second support region 60 and the first 52 and second 54 recesses. Second support region 60 cinctures second recess 54. A portion 62 of chuck body 42 in superimposition with second recess 54 is transparent to radiation having a predetermined wavelength, such as the wavelength of the actinic radiation mentioned above. To that end, portion 62 is made from a thin layer of transparent material, such as glass. However, the material from which portion 62 is made may depend upon the wavelength of radiation produced by radiation source 22, shown in Fig. 2. Portion 62 extends from second side 48 and terminates proximate to second recess 54 and should define an area at least as large as an area of mold 28 so that mold 28 is in superimposition therewith. Formed in chuck body 42 are one or more throughways, shown as 64 and 66. One of the throughways, such as throughway 64 places first recess 52 in fluid communication with side surface 50. The remaining throughway, such as throughway 66, places second recess 54 in fluid communication with side surface 50.

[0040] It should be understood that throughway 64 may extend between second side 48 and first recess 52, as well. Similarly, throughway 66 may extend between second side 48 and second recess 54. What is desired is that throughways 64 and 66 facilitate placing recesses 52 and

54, respectively, in fluid communication with a pressure control system, such a pump system 70.

[0041] Pump system 70 may include one or more pumps to control the pressure proximate to recesses 52 and 54, independently of one another. Specifically, when mounted to chuck body 42, template 26 rests against first 58 and second 60 support regions, covering first 52 and second 54 recesses. First recess 52 and a portion 44a of template 26 in superimposition therewith define a first chamber 52a. Second recess 54 and a portion 44b of template 26 in superimposition therewith define a second chamber 54a. Pump system 70 operates to control a pressure in first 52a and second 54a chambers. Specifically, the pressure is established in first chamber 52a to maintain the position of the template 26 with the chuck body 42 and reduce, if not avoid, separation of template 26 from chuck body 42 under force of gravity. The pressure in the second chamber 54a may differ from the pressure in the first chamber 52a to, inter alia, reduce distortions in the template 26 that occur during imprinting, by modulating a shape of template 26. For example, pump system 70 may apply a positive pressure in chamber 54a to compensate for any upward force R that occurs as a result on imprinting layer 34 contacting mold 28. Additionally, pump system 70 may apply a positive pressure in chamber 54a to compensate for any upward force R that occurs as a result on imprinting layer 34 contacting mold 28. In this manner, produced is a pressure differential between differing regions of side 46 so that bowing of template 26 and, therefore, mold 28 under force R is attenuated, if not avoided. Coupled to template 26 is a means for varying dimensions of the same in X and Y directions,

with the understanding that the Y-direction is into the plane of Fig. 8. The means for varying dimensions is shown schematically as actuator device 72.

[0042] Referring to Figs. 8, 11 and 12, in the present example the actuator device 72 includes first and second bodies 74 and 76, mounted on opposite sides of chuck body 42, all of which are mounted to a flexure system 18c. At least one of bodies body 74 and 76 includes one or more chambers, shown in body 74 as 74a. Disposed within chamber 74a is an actuator arm. A first member 74c of actuator arm 74b is connected to body 74 to reciprocate about an axis 74d. First member 74c extends from axis 74d along the Z direction and terminates in a second member 74e. Second member 74e extends from first member 74c along the X direction and terminates in a contact member 74f. At least one bladder is disposed within chamber 74a. In the present example two bladders 78a and 78b are disposed in chamber on opposite sides of first member 74c. Specifically, bladder 78b disposed between a first sidewall 74g of body 74 and first member 74c, and bladder 78b is disposed between a second side wall 74h of body and first member 74c. Each of bladders 78a and 78b has a volume that may be selectively varied in response to introduction of a fluid therein. To that end, each bladder 78a and 78b is in fluid communication with pump system 70.

[0043] Disposed opposite to contact member 74f is contact member 76f and spaced-apart a distance D_1 . It is not necessary for contact member 76f to be coupled to move with respect to body 76. As a result, contact member 76f may be rigidly attached to body 76. As shown, however, contact member is shown connected to a second portion of actuator arm 76, and first member 76c of

actuator arm 76b is connected to body 76 to reciprocate about an axis 76d. First member 76c extends from axis 76d along the Z direction and terminates in a second member 76e. Second member 76e extends from first member 76c along the X direction and terminates in a contact member 76f. At least one bladder is disposed within chamber 76a. In the present example two bladders 80a and 80b are disposed in chamber 76a on opposite sides of first member 76c. Specifically, bladder 80a is disposed between a first sidewall 76g of body 76 and first member 76c, and bladder 80b is disposed between a second sidewall 76h of body 76 and first member 76c. Each of bladders 80a and 80b has a volume that may be selectively varied in response to introduction of a fluid therein. To that end, each bladder 80a and 80b is in fluid communication with pump system 70.

[0044] During operation, template 26 is disposed between contact members. Typically the distance D_1 is established to be slightly smaller than the distance between the opposed regions of perimeter surface 26a of template 26 in contact therewith. In this manner, template 26 is described as being compressively pre-loaded. To compress template 26, one or both of bladders 78a and 80a may be inflated to increase the volume thereof. Expansion of bladder 78a causes actuator arm 74b to move about axis 74d toward sidewall 74h, thereby decreasing the magnitude of distance D_1 . Expansion of bladder 80a causes actuator arm 76b to move about axis 76d toward sidewall 76h, thereby decreasing the magnitude of distance D_1 . To reduce the compression forces on template 26, the volume of bladders 78a and 80a may be reduced to return to nominal size. To expand the distance D_1 so that template 26 is not compressively pre-

loaded, and/or may be easily decoupled from actuator device 72, one or both of bladders 78b and 80b may be expanded. Expansion of bladder 78b causes actuator arm 74b to move about axis 74d toward sidewall 74g, thereby increasing the magnitude of distance D_1 . Expansion of bladder 80b causes actuator arm 76b to move about axis 76d toward sidewall 76g, thereby increasing the magnitude of distance D_1 . Expansion of bladders 78b and 80b may also occur as the volume of bladders 78a and 80a is decreased. By appropriately controlling a rate at which one or more of bladders 78b and 80b are expanded and one or both of bladders 78b and 80b are deflated, the time required to return substrate to a compressively pre-loaded state may be reduced

[0045] Referring to both Figs. 11 and 12, a problem encountered during operation concerned a force applied against side walls 74g and 76g when large compression forces were applied to perimeter surface 26a. In these situations expansion of bladder 78a exerted a force applied to side wall 76g and expansion of bladder 80a exerted a force on side wall 76g. The forces exerted on one or both of side walls 74g and 76g resulted in bending moment on chuck body 42, which is transmitted onto template 26. Ideally, template 26 should be subjected to purely compressive forces, with bending forces being substantially minimized, if not avoid entirely. Bending forces on substrate are problematic in that it results in pattern distortion. Substantially reduce the aforementioned bending moment, a compression ring 79 is provided. Compression ring 79 surrounds an area 81 and includes a surface 79a facing the area 81. Bodies 74 and 76 are connected to surface 79a and disposed opposite one another. In this manner, the force exerted by bladder

78a on sidewall 74g creates an equal and opposite force on a region of compression ring 79 disposed opposite to body 74. Similarly, the force exerted by bladder 80a on sidewall 76g creates an equal and opposite force on a region of compression ring 79 disposed opposite to body 76. To maximize the effectiveness of compression ring 79, a neutral axis 79a thereof, is closely aligned with a neutral axis A of template 26.

[0046] It is possible to employ actuator device 72 to expand template 26, as well. To that end, contact members 74f and 76f would be fixedly attached to perimeter surface 26a. This may be achieved, for example, with the use of adhesives. The second members 74e and 76e would then be coupled to contact members, 74f and 76f, respectively by, for example, a threaded coupling and/or adhesives. Tensile forces would be applied to template 26 by expanding one or both of bladders 78b and 80b.

[0047] An advantage with the present design is that the entire actuator device 72 is positioned to lie on one side of mold 28 so as to be spaced-apart from a plane in which mold surface 28c lies. This is beneficial in preventing contact between the components of actuator device 72 and a wafer 30, shown in Fig. 5, during imprint processes. Additionally, by providing a relatively long firm member 74c and 76c, that area upon which a force may be exerted by bladders 74a, 74b, 76a and 76b may be substantially increased. This facilitates increasing the per unit area of force applied to perimeter surface 26a by contact members 74f and 76f. The amplification of the force per unit area exerted by contact member 74f is a function of the ratio of two areas: the area of perimeter surface 26a upon which contact members 74f

exerts a force and the area of first member 74fc over which one of bladders 78a and 78b exerts a force. Similarly, the amplification of the force per unit area exerted by contact member 76f is a function of the ratio of two areas: the area of perimeter surface 26a upon which contact members 76f exerts a force and the area of first member 76c over which one of bladders 80a and 80b exerts a force.

[0048] Bladders 78a, 78b, 80a, and 80b provide an additional advantage of avoiding localized force concentration on actuator arms 74b and 76b due to, for example, roughness of the surface in contact therewith. Specifically, the surface roughness of actuator arms 74b and 76b may result in an uneven distribution of the force applied thereon by bladders 78a, 78b, 80a, and 80b. As a result, there can be localized surface concentrations of the force created by the bladders 78a, 78b, 80a, and 80b that may result in non-linear compression. Bladders 78a, 78b, 80a, and 80b reduce, if not avoid, this problem by being formed of compliant material that takes the shape of the area against which contact is made. As a result, an even distribution of forces is exerted on over the contact area. For similar reasons, it may be desired to form contact members 74f and 76f from compliant material so that the same forms a profile that matches the profile of the perimeter surface 26a that comes in contact therewith.

[0049] An additional benefit provided by using compliant bladders 78a, 78b, 80a, and 80b is that the same compensates for any non-planarity and/or roughness over the area of perimeter surface 26a, referred hereafter as surface anomalies, that comes into contact with the contact members 74f and 76f. Specifically,

bladders 78a, 78b, 80a, and 80b may conform to any distortion of first members 74c and 76c result from any bending moment exerted thereupon by contact members 74f and 76f. To further increase compliance with any surface anomalies body 74 may include a plurality of contact members, shown as 174f, 274f, 374f and 474f, each of which is attached to a separate actuator arm (not shown) that is mounted to body 74 as discussed above with respect to actuator arm 74b. Bladders 78a and 78b could facilitate movement of contact members as discussed above with respect to contact member 74f. Similarly, body 76 may include a plurality of include a plurality of contact members, shown as 176f, 276f, 376f and 476f, each of which is attached to a separate actuator arm (not shown) that is mounted to body 76, as discussed above with respect to actuator arm 76b. Bladders 80a and 80b could facilitate movement of contact members 176f, 276f, 376f and 476f with respect to contact member 76f.

[0050] Referring to Figs. 12 and 14, further compliance with surface anomalies may be achieved by allowing independent control over the movement of the plurality of contact members 174f, 274f, 374f, 474f, 176f, 276f, 376f and 476f. To that end, bladder 78a may be replaced with a plurality of bladders 178a, 278a, 378a, 478a, each of which is in fluid communication with pump system 70. Each of the plurality of bladders 178a, 278a, 378a, 478a is coupled to move one of contact members 174f, 274f, 374f, 474f that differs from the contact members 174f, 274f, 374f, 474f that the remaining bladders 178a, 278a, 378a, 478a are coupled to move. For the same reasons, bladder 80a may be replaced with a plurality of bladders 180a, 280a, 380a, 480a, each of which is in fluid communication with pump system 70.

Each of bladders 180a, 280a, 380a, 480a is coupled to move one of contact members 176f, 276f, 376f, 476f that differs from the contact members 176f, 276f, 376f, 476f that the remaining bladders 180a, 280a, 380a, 480a are coupled to move. Although the foregoing has been discussed with replacing bladders 78a and 80a with a plurality of bladders, bladders 78b and 80b may also be replaced with a plurality of bladders to achieve independent control over contact members 174a, 274f, 374f, 474f, 176f, 276f, 376f and 476f when applying a tensile force to template 26.

[0051] An additional benefit with providing independent control over the movement of the plurality of contact members 174f, 274f, 374f, 474f, 176f, 276f, 376f and 476f is that it facilitates compensation for errors caused by anisotropic thermal expansion of template 26. Thus, it may be desirable to obtain an accurate determination of the temperature of template 26 and include information derived therefrom to determine the proper compression applied among contact members 174f, 274f, 374f, 474f, 176f, 276f, 376f and 476f.

[0052] Referring to Figs. 12, 14 and 15 although the foregoing has discussed use of bladders, it is possible to replace any of the bladders 78a, 78b, 80a, 80b, 178a, 278a, 378a, 478a, 180a, 280a, 380a and 480a with a piezo actuator, four of which are shown as 500, 502, 504 and 506. The contact region between each, shown as 500a, 502a, 504a and 506a is allowed to flex with respect of the interface of contact regions 500a, 502a, 504a and 506a with perimeter surface 26. To that end, each of piezo actuators is coupled to body 76 via flexures 500b, 502b, 504b and 506b, respectively. Working synergistically, piezo actuators 500, 502, 504 and 506

may be employed to compensate for surface anomalies and bladders 178a, 278a, 378a and 478a may be employed to compensate for large mean errors for differing templates coupled to chuck body 42. This facilitates maintaining template 26 centering respect to a machine coordinate frame.

[0053] Although piezo actuators are shown in combination with the plurality of bladders 178a, 278a, 378a and 478a, any combination piezo actuators and bladders may be employed in actuator device 72. For example, only one piezo actuator may be employed on one body for example, body, 74, with body 76 contact one or more contact members being rigidly attached thereto or having including any of the bladder combinations shown in Figs. 11, 12 and 13. Also, it is possible that all bladders associated with compression device be replaced with piezo actuators.

[0054] Referring to Fig. 11 may be desired to include an additional pair of contact members 73 and 75 to vary a distance therebetween D_2 in a direction orthogonal to the direction in which distance D_1 is varied. In this manner the dimension of template 26 may be varied in two dimensions. This is particularly useful in overcoming Poisson's effect. Poisson's effect may result in linear coupling of template 26 that may necessitate activating actuators to vary both distances D_1 and D_2 . Specifically, the Poisson ratio is the ratio between the tensile strain caused in the Y and Z directions in template 26 to the compressive strain imparted to template 26 in the X direction. Typical numbers are in the range of 0.1-0.4. Were template 26 formed from fused silica the ratio is approximately 0.16. A dimensional change that is purely in the X direction, therefore, i.e., with no dimensional

change in the Y direction being desired, may necessitated activation of actuators to vary both distanced D_1 and D_2 , to compensate for Poisson's effect. With any of the above-described configurations of actuator device 72, a force may be applied to template 26 to vary the dimensions of the same and reduce distortions in the pattern recorded into imprinting layer 34, shown in Fig. 2.

[0055] Specifically, distortions in the pattern recorded into imprinting layer 34 may arise from, *inter alia*, dimensional variations of imprinting layer 34 and wafer 30. These dimensional variations, which may be due in part to thermal fluctuations, as well as, inaccuracies in previous processing steps that produce what is commonly referred to as magnification/run-out errors. The magnification/run-out errors occur when a region of wafer 30 in which the original pattern is to be recorded exceeds the area of the original pattern. Additionally, magnification/run-out errors may occur when the region of wafer 30, in which the original pattern is to be recorded, has an area smaller than the original pattern. The deleterious effects of magnification/run-out errors are exacerbated when forming multiple layers of imprinted patterns, shown as imprinting layer 124 in superimposition with patterned surface 32a, shown in Fig. 6. Proper alignment between two superimposed patterns is difficult in the face of magnification/run-out errors in both single-step full wafer imprinting and step-and-repeat imprinting processes.

[0056] Referring to Figs. 16 and 17, a step-and-repeat process includes defining a plurality of regions, shown as, a-1, on wafer 30 in which the original pattern on mold 28 will be recorded. The original pattern on mold

28 may be coextensive with the entire surface of mold 28, or simply located to a sub-portion thereof. The present invention will be discussed with respect to the original pattern being coextensive with the surface of mold 28 that faces wafer 30. Proper execution of a step-and-repeat process may include proper alignment of mold 28 with each of regions a-1. To that end, mold 28 includes alignment marks 114a, shown as a "+" sign. One or more of regions a-1 includes fiducial marks 110a. By ensuring that alignment marks 114a are properly aligned with fiducial marks 110a, proper alignment of mold 28 with one of regions a-1 in superimposition therewith is ensured. To that end, machine vision devices (not shown) may be employed to sense the relative alignment between alignment marks 114a and fiducial marks 110a. In the present example, proper alignment is indicated upon alignment marks 114a being in superimposition with fiducial marks 110a. With the introduction of magnification/run-out errors, proper alignment becomes very difficult.

[0057] However, in accordance with one embodiment of the present invention, magnification/run-out errors are reduced, if not avoided, by creating relative dimensional variations between mold 28 and wafer 30. Specifically, the temperature of wafer 30 is varied so that one of regions a-1 defines an area that is slightly less than an area of the original pattern on mold 28. Thereafter, the final compensation for magnification/run-out errors is achieved by subjecting template 26, shown in Fig. 8, to mechanical compression forces using actuator device 72, which are in turn transferred to mold 28 shown by arrows F_1 and F_2 , orientated transversely to one another, shown in Fig. 17. In this manner, the area of the original

pattern is made coextensive with the area of the region a-1 in superimposition therewith.

[0058] Referring to both Figs. 5 and 8, subjecting template 26 to compressive forces, however, modulates the shape of the same through bending action. Bending of template 26 may also introduce distortions in the pattern imprinted into imprinting layer 34. The pattern distortions attributable to bending of template 26 may be reduced, if not prevented, by positioning actuator device 72 so that the bending of template 26 is controlled to occur in a desired direction. In the present example, actuator device 72 is positioned to compress template 26 so as to bow in a direction parallel to, and opposite of, force R. By controlling the bending of template 26 in this manner, chucking system 40 may be employed to counter the bending force, B, so as to establish mold 28 to be a desired shape, e.g., arcuate, planar and the like. Pump system 70 may be employed to pressurize chamber 54a appropriately to that end. For example, assuming bending force, B, is greater than force R, pump system 70 would be employed to evacuate chamber 54a with sufficient vacuum to counter the bending force B. Were bending force B weaker than force, R, pump system 70 would be employed to pressurize chamber 54a appropriately to maintain planarity of mold 28, or any other desired shape. The exact pressure levels may be determined with *a priori* knowledge of the forces R and B which then may be analyzed by a processor (not shown) that may be included in pump system 70 to pressurize chambers 52a and 54a to the appropriate levels. Also, the forces R and B may be sensed dynamically using known techniques so that the pressure within chambers 52a and 54a may be established dynamically during operation to maintain

template 26 with a desired shape. An added benefit is that the pressure in one or both chambers 52a and 54a may be established to be a positive pressure, thereby facilitating removal of template 26 from chuck body 42. This also may be accomplished under processor control, or manually.

[0059] Referring again to Fig. 8, when compressing template 26 with actuator device 72, relative movement between template 26 and support regions 58 and 60 occurs along the X and Y axes. As a result, it is desired that support regions 58 and 60 have surface regions 58a and 60a, respectively, formed thereon from a material adapted to conform to a profile of said template 26 and resistant to deformation along the X and Y axes. In this manner, surface regions 58a and 60a resist relative movement of template 26 with respect to chuck body 42 in the X and Y directions.

[0060] Referring to Figs. 8 and 18, in another embodiment, chuck body 142 may include one or more walls, or baffles, shown as 142a, 142b, 142c and 142d extending between first and second support regions 158 and 160. In this fashion, walls/baffles 142a, 142b, 142c and 142d segment recess 152 into a plurality of sub-regions 152a, 152b, 152c and 152d that function as sub-chambers once template 26 is placed in superimposition therewith. Sub-chambers 152a, 152b, 152c and 152d may be fluid-tight which would result in each have a throughway (not shown) placing the same in fluid communication with pump system 70. Alternatively, or in conjunction therewith, sub-chambers 152a, 152b, 152c and 152d may not form fluid-tight chambers once template 26 is placed in superimposition therewith. Rather walls 142a, 142b, 142c and 142d would be spaced apart from template 26 to

function as a baffle for fluid transfer across the same. As a result, with the appropriate pressure level being provided by pump system 70 to recess 152, a pressure differential could be provided between sub-chambers 152a, 152b, 152c and 152d, as desired.

[0061] Referring to both Figs. 2 and 18, providing walls/baffles 142a, 142b, 142c and 142d this configuration, sub-regions 152a, 152b, 152c and 152d may be concurrently provided with differing pressure levels. As a result, the amount of force exerted on template 26 when being pulled-apart from imprinting layer 34 may vary across the surface of template 26. This allows cantilevering, or peeling-off of template 26 from imprinting layer 34 that reduces distortions or defects from being formed in imprinting layer 34 during separation of template 26 therefrom. For example, sub-chamber 152b may have a pressure established therein that is greater than the pressure associated with the remaining sub-chambers 152a, 152c and 152d. As a result, when increasing distance "d" the pulling force of the portion of template 26 in superimposition with sub-chambers 152a, 152c and 152d is subjected to is greater than the pulling force to which the portion of template 26 in superimposition with sub-chamber 152b is subjected. Thus, the rate that "d" increases for the portion of template 26 in superimposition with sub-chambers 152a, 152c and 152d is accelerated compared to the rate at which "d" increases for the portion of template 26 in superimposition with sub-chamber 152b, providing the aforementioned cantilevering effect.

[0062] In yet another embodiment, shown in Fig. 19, chuck body 242 includes a plurality of pins 242a projecting from a nadir surface 252a of out recess 252.

Pins 242a provide mechanical support for the wafer (not shown] retained on chuck body 242 via vacuum. This enables support regions 258 and 260 to have surface regions 258a and 260a, respectively, formed from material that is fully compliant with the surface (not shown) of the wafer (not shown) resting against support regions 258 and 260. In this manner, surface regions 258a and 260a provide a fluid-tight seal with the wafer (not shown) in the presence of extreme surface variation, e.g., when particulate matter is present between the surface (not shown) of the wafer (not shown) and the surface regions 258a and 260a. Mechanical support of the wafer (not shown) in the Z direction need not be provided by surface regions 258a and 260a. Pins 242a provide this support. To that end, pins 242a are typically rigid posts having a circular cross-section.

[0063] Referring to Figs. 16, 17 and 20, in operation, an accurate measurement of wafer 30 in an X-Y plane is undertaken at step 200. This may be achieved by sensing gross alignment fiducials 110b present on wafer 30 using machine vision devices (not shown) and known signal processing techniques. At step 202, the temperature of wafer 30 may be varied, i.e., raised or lowered, so that the area of one of regions a-1 is slightly less than an area of the original pattern on mold 28. The temperature variations may be achieved using a temperature controlled chuck or pedestal (not shown) against which wafer 30 rests. The area of each of regions a-1 can be determined by measurement of a change in distance between two collinear gross alignment fiducials 110b.

[0064] Specifically, a change in the distance between two gross alignment fiducials 110b collinear along one of the X or Y axes is determined. Thereafter, this change

in distance is divided by a number of adjacent regions a-1 on the wafer 30 along the X-axis. This provides the dimensional change of the areas of regions a-1 attributable to dimensional changes in wafer 30 along the X-axis. If necessary the same measurement may be made to determine the change in area of regions a-1 due to dimensional changes of wafer 30 along the Y-axis. However, it may also be assumed that the dimensional changes in wafer 30 may be uniform in the two orthogonal axes, X and Y.

[0065] At step 204, compressive forces, F_1 and F_2 , are applied to mold 28 to establish the area of the original pattern to be coextensive with the area of one of the regions a-1 in superimposition with the pattern. This may be achieved in real-time employing machine vision devices (not shown) and known signal processing techniques, to determine when two or more of alignment marks 114a are aligned with two or more of fiducial marks 110a. At step 206, after proper alignment is achieved and magnification/run-out errors are reduced, if not vitiated, the original pattern is recorded in the region a-1 that is in superimposition with mold 28, forming the recorded pattern. It is not necessary that compression forces F_1 and F_2 have the same magnitude, as the dimensional variations in either wafer 30 or mold 28 may not be uniform in all directions. Further, the magnification/run-out errors may not be identical in both X-Y directions. As a result, compression forces, F_1 and F_2 may differ to compensate for these anomalies. Furthermore, to ensure greater reduction in magnification/run-out errors, the dimensional variation in mold 28 may be undertaken after mold 28 contacts

imprinting layer 124, shown in Fig. 6. However, this is not necessary.

[0066] Referring again to Figs. 6, 16 and 17, the alignment of mold 28 with regions a-1 in superimposition therewith may occur with mold 28 being spaced-apart from imprinting layer 124. Were it found that the magnification/run-out errors were constant over the entire wafer 30, then the magnitude of forces F_1 and F_2 could be maintained for each region a-1 in which the original pattern is recorded. However, were it determined that the magnification/run-out errors differed for one or more regions a-1, steps 202 and 204, shown in Fig. 15, would then be undertaken for each region a-1 in which the original pattern is recorded. It should be noted that there are limits to the relative dimensional changes that may occur between wafer 30 and mold 28. For example, the area of the regions a-1 should be of appropriate dimensions to enable pattern on mold 28 to define an area coextensive therewith when mold 28 is subject to compression forces F_1 and F_2 , without compromising the structural integrity of mold 28.

[0067] Referring to Figs. 5 and 21, in accordance with another embodiment of the present invention, accurate measurement of wafer 30 in an X-Y plane is undertaken at step 300. At step 302, the dimensions of one of regions a-1 in superimposition with mold 28 is determined. At step 304 it is determined whether the area of one of regions a-1 in superimposition with mold 28 is larger than the area of the pattern on mold 28. If this is the case, the process proceeds to step 306, otherwise the process proceeds to step 308. At step 308, mold 28 is placed in contact with the region a-1 in superimposition therewith, and the requisite magnitude of compressive

forces F_1 and F_2 is determined to apply to mold 28 to ensure that the area of pattern is coextensive with the area of this region a-1. At step 310, compressive forces F_1 and F_2 are applied to mold 28. Thereafter, mold 28 is spaced-apart from the region a-1 in superimposition with mold 28 and the process proceeds to step 312 where it is determined whether there remain any regions a-1 on wafer 30 in which to record the original pattern. If there are, the process proceeds to step 314 wherein mold is placed in superimposition with the next region and the process proceeds to step 304. Otherwise, the process ends at step 316.

[0068] Were it determined at step 304 that the region a-1 in superimposition with mold 28 had an area greater than the area of the pattern, then the process proceeds to step 306 wherein the temperature of mold 28 is varied to cause expansion of the same. In the present embodiment, mold 28 is heated at step 306 so that the pattern is slightly larger than the area of region a-1 in superimposition therewith. Then the process continues at step 310.

[0069] The embodiments of the present invention described above are exemplary. Many changes and modifications may be made to the disclosure recited above, while remaining within the scope of the invention. For example, by pressurizing all chambers formed by the chuck body-substrate combination with positive fluid pressure, the substrate may be quickly released from the chuck body. Further, many of the embodiments discussed above may be implemented in existing imprint lithography processes that do not employ formation of an imprinting layer by deposition of beads of polymerizable material. Exemplary processes in which differing embodiments of the

present invention may be employed include a hot embossing process disclosed in United States patent number 5,772,905, which is incorporated by reference in its entirety herein. Additionally, many of the embodiments of the present invention may be employed using a laser assisted direct imprinting (LADI) process of the type described by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, Nature, Col. 417, pp. 835-837, June 2002. Therefore, the scope of the invention should be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.